

Urban form and travel behavior: ~~North European research reviewed against an international background~~ experience from a Nordic context

Abstract

~~This article surveys the state of knowledge results of research carried out in the Nordic countries about on the influence of various aspects of urban form and settlement patterns on travel behavior, based in particular on North European research but with a and discusses these results in the view also of studies of carried out in other European, American, Australian and Asian cities countries. There is quite overwhelming evidence that urban spatial structures matter to travel behavior. However, whereas much of the research in America and parts of Europe has focused on the influences of local neighborhood characteristics on travel, the Nordic research shows effects on travel behavior mainly from urban form characteristics at a higher geographical scale: the overall population density within continuous urban areas, and the locations of residences and workplaces relative to the city-level or metropolitan center structure.~~

~~The mechanisms through which these influences operate appear to be present in a wide international context, indicating a high degree of generality. Urban planners aiming to reduce car dependency and urban motoring should seek to avoid urban sprawl, increase the proportions of the population living and working in the inner and central areas of the city, and ensure a sufficiently high density in new developmental areas to facilitate a good provision of local service and a good public transport provision.~~

1. Introduction

~~This~~ This article surveys the results of research carried out in the Nordic countries on the influence of various aspects of urban form and settlement patterns on travel behavior, and discusses these results in the view of studies carried out in a wider international context. This article surveys the state of knowledge about the influence of various aspects of urban form and settlement patterns on travel behavior. The focus of the article is on the influence of urban land use (the geographical distribution and density of the building stock and the urban functions therein) and settlement patterns on transportation variables. The paper does not directly address impacts of transport infrastructure such as road provision, public transport service level, and the availability of parking.

Depending on the policy context, different studies of relationships between land use and travel have focused on different transport and travel parameters, such as trip frequency, trip distances, choices of travel modes, or overall vehicle kilometers traveled. Reflecting a perspective of environmentally sustainable mobility and greenhouse gas mitigation, the transport variables focused on in the present article are overall traveling distances, traveling distances by mode, modal shares, and energy consumption. Most of the studies reviewed are confined to travel, thus omitting freight. Some of the studies of energy consumption still include energy used for transportation of both persons and goods. In spite of the intuitively obvious fact that average distances to facilities will normally be lower in dense cities and inner city urban districts and the requirement of a certain population density for public transport to provide a high level of service, as well as a large number of empirical studies demonstrating effects of built environment characteristics on travel, doubts are still

sometimes raised about the existence of any such influences (see, e.g., Breheny, 1994; Gordon & Richardson, 1997; Williams et al., 2000; Headicar, 2003; Bruegmann, 2005). As will be shown below, the evidence that urban spatial structures matter to travel behavior is quite overwhelming. Yet, in the literature, there may be disagreement as to which urban form characteristics are the most influential ones. The studies also differ in terms of their investigated aspects of travel and transportation.

Several authors have summarized main findings from individual studies of associations between urban form characteristics (e.g. Stead & Marshall, 2001; Cao et al., 2009; Ewing & Cervero, 2001 and 2010; Lefèvre, 2010). In some cases, such summarizing has been carried out as so-called meta-analyses, where the quantified effects of urban form variables on travel behavior variables in different studies have been used as input data for statistical analyses of the average strengths of these relationships across the individual studies (Ewing & Cervero, 2010). While illustrating the overwhelming majority of studies showing an influence of urban form on travel, compared to the few studies where no such influence has been found, such meta-analyses still have clear limitations. For one thing, they do not distinguish between methodologically strong and weak studies, e.g. in terms of data quality as well as to and the inclusion of relevant factors of influence (Zegras, 2010). Although all studies in Ewing & Cervero's (2010) meta analysis include socioeconomic and demographic variables, only a few of them have addressed attitude based self selection. Furthermore, it is often not clear whether or not the effect of a particular urban form characteristic (e.g. the design of the local street network) in a study included in the meta-analysis has been controlled for other relevant urban form variables (e.g. the distance from the dwelling to downtown). Finally, in spite of there is also an overall dominance of studies from USA in Ewing & Cervero's meta analysis, the geographical, social, cultural and economic contexts are of course different in the various investigated cities and urban environments, thus limiting the usefulness of calculating average effects of urban form variables on travel. The American dominance of in most existing surveys of the status of knowledge. This in itself justifies the purpose of the present article: to provide an overview of the main urban form characteristics found to influencing travel behavior mainly within a (North) European/Nordic context, (yet with some examples also from studies of American, Australian and Asian cities), based on a critical assessment of the methods, data sources and theoretical underpinnings of the research results. Similarities and differences between the findings of the Nordic studies and research carried out in other parts of the world will be discussed, and possible explanations of any divergences will be suggested. The focus of this article is on the influence of urban land use (the geographical distribution and density of the building stock and the urban functions therein) and settlement patterns on transportation variables. The article does not directly address impacts of transport infrastructure such as road provision, public transport service level, and the availability of parking. These parameters are, however, strongly related to some of the urban form characteristics dealt with in the article. For example, in a dense city, less space will be available for parking and urban highways, and conversely, the provision of a high road and parking capacity in itself makes the city less dense and also facilitates urban sprawl. (For an overview of the impacts of transport infrastructure characteristics on travel behavior, see Mogridge (1997); Næss et al. (2001); Noland & Lem (2002) and Litman (2009)).

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2. Theoretical reasons why land use must be expected to influence travel

Theories of transport geography and transport economy consider the travel between different destinations to be influenced on the one hand by the reasons people may have for going to a place, and on the other hand by the costs and inconvenience involved when traveling to this location (Jones, 1978). Urban form impacts prices of travel, which in turn influence consumption of travel (Boarnet & Crane, 2001). By determining the distances between locations where different activities may be carried out, and by facilitating different modes of travel, urban form characteristics make up a set of conditions facilitating some kinds of travel behavior while discouraging other types of travel behavior. Needless to say, the causes of travel behavior also include personal characteristics, such as age, sex, affluence level, employment, as well as norms, values, lifestyles, acquaintances and social obligations. The emerging transportation pattern (trip frequencies, choices of destinations, modes of traveling and trip routes) is a result of people's resources, needs and wishes, modified by the constraints and opportunities given by urban form characteristics as well as other structural conditions of society.

For the city as a whole, high population density implies shorter average distances between residences, workplaces and service facilities than in a city with a dispersed pattern of development. The gain in the form of travelling distances includes shorter trips from home to work and service facilities, better opportunities for linking different trip purposes, and shorter trips when visiting friends and relatives living in the same city. Furthermore, a high population density facilitates more frequent public transport departures and shorter walking distances to bus stops and metro stations. Because distances between activities are shorter in dense cities, a higher proportion of the destinations will also be within walking or cycling distances. Furthermore, in dense urban areas, streets are usually narrower and there is less space available for parking than in less densely developed areas.

In spite of decentralizing trends, most European cities still have a higher concentration of workplaces, retail, public agencies, cultural events and leisure facilities in the historical urban center and its immediate surroundings than in the peripheral parts of the urban area (among others, Newman and Kenworthy, 1999:94-95; Author, 2006). The inner and central parts of the metropolitan area include the largest supply of work opportunities, the broadest range of commodities in the shops, as well as the highest diversity of service facilities. For residents of the inner and central parts of the city the distances to this concentration of facilities will be short. Inner-city residents could thus be expected on average to make shorter daily trips than their outer-area counterparts, with a higher proportion of destinations within acceptable walking or biking distance. Local-scale urban design principles, such as street pattern, availability of sidewalks and bike paths etc. and aesthetic neighborhood qualities, can influence the attractiveness of non-motorized travel modes and can for some travel purposes also affect trip destinations. Such characteristics have been at the core of the interest of American studies of the influence of the built environment on travel behavior.

A central location of employment opportunities could also be expected to contribute to lower energy consumption for transport. The accessibility by public transport is usually highest in the central parts of the city. In addition, congestion and scarcity of parking space in downtown areas may cause a number of potential car commuters to leave their car in the garage at home. Distinct

from this, suburban jobs are often poorly accessible by transit, while access by car is easy with less congested roads and usually ample parking.

As can be seen, there are good theoretical reasons to assume urban transport to be influenced by urban form characteristics. Doubts are still sometimes raised about the existence of any influences of urban form on travel behavior (see, e.g., Breheny, 1994; Gordon & Richardson, 1997; Williams et al., 2000; Headicar, 2003; Bruegmann, 2005). However, as will be shown in the following sections, the evidence that urban spatial structures matter to travel behavior is quite overwhelming. There may still be disagreement as to which urban form characteristics are the most influential ones.

~~There may, however, also be e~~Counteracting mechanisms may also be operating. For example, the shorter distances between functions facilitated by dense cities or inner-city residential locations could be utilized by opting for a wider range of workplaces, shops and residences and by increasing the frequency of trips, rather than reducing the amount of travel (Crane, 1996). Similarly, the money and time saved by living close to daily destinations could be spent on making longer leisure trips, perhaps by airplane (Vilhelmson, 1990). In the literature on the effects of environmental policy measures, such counteracting mechanisms are referred to as *rebound effects* (Nørgaard, 2008; see also Holden, 2007 and Author, 2006b). It is important to be aware that the existence of such (partly) compensatory mechanisms does not reduce the causal influence of urban form on travel. Urban travel is influenced by a multitude of causes, among which some may reinforce each other and others may counteract each other. The causal influences of urban form on individuals' travel behavior thus exist independently of whether or not, e.g., any tendency among inner-city residents of making a higher number of holiday trips by airplane is counteracted by heavier CO₂ taxes on flights or is allowed to operate unrestricted (cf. Bhaskar, 1998; Author, 2004). Causality is not the same as correlation and need not manifest itself as 'event regularities'. At a city scale, though, the causal influence of urban form characteristics on aggregate travel behavioral patterns requires the causal mechanisms by which urban form influences travel behavior at the individual level to be on average strong enough to outweigh any counteracting mechanisms. The emergence of city-level causal relationships between urban form and travel thus presupposes a certain degree of event regularities in the form of more or less strong correlations between urban form characteristics and the travel behavior of the city's inhabitants (Author, 2004).

3. Methods and sources of knowledge

Urban planners and urban geographers have for a long time presupposed that urban land use influences transport and travel behavior. In particular, the oil embargos in 1973/74 and 1979/1980 triggered considerable interest in research into relationships between urban form and transportation (Real Estate Research Corporation, 1974; Needham, 1977; Burchell & Listokin, 1982; Owens, 1986). Some of these studies were purely theoretical analyses. Several other early studies were based on model simulations of hypothetical land use scenarios. They illustrated and synthesized already existing assumptions about transportation consequences of alternative urban structures, but could of course not be used to investigate whether the model's assumptions about the influences between its variables were correct. The first empirical studies into the land use – transport relationship (among others, Keyes, 1976 ~~and 1982~~; Newman & Kenworthy, 1989) were comparisons of transportation fuel usage at an aggregate level (typically between cities or metropolitan areas). Later on, an increasing number of studies have been carried out at a disaggregate level, with households or individuals as units of analysis. At first, few of these studies took into account other factors of influence than the urban structural variables the studies were

focused on. Gradually, several empirical investigations have been carried out, incorporating urban form variables as well as demographic and socio-economic factors in the analyses. Although most studies carried out during the latest couple of decades have attempted to control for demographic and socioeconomic variables, a number of authors still hold that the possibility that people base their choice of residence partly on preference for a particular travel mode precludes any firm conclusions about the influence of residential location on travel (see, e.g., Kitamura et al., 1997; Boarnet & Crane, 2001; Krizek, 2003; Schwanen & Mokhtarian, 2004; [Schreiner & Holz-Rau, 2007](#); Cao, Mokhtarian & Handy, 2009). A growing number of recent studies have therefore explicitly addressed this so-called 'self-selection problem', mostly often by including variables measuring residential preferences and/or transport attitudes but also using other methodologies such as instrumental variables, joint discrete choice models, structural equations models, and longitudinal designs. However, statistical analyses, even with inclusion of the relevant socioeconomic and attitudinal variables, cannot themselves establish that causality exists between urban form and travel. In a few studies, the traditional quantitative travel survey approach has therefore been combined with qualitative interviews in order to identify the more detailed mechanisms through which urban structure affects travel behavior.

4. The Nordic studies reviewed

In the following, a total of 31 Nordic studies on the influence of urban form on travel carried out during the period since 1982 will be reviewed. These studies include, as far as the author is aware of, all published empirical research on the topic carried out in a Nordic context during the latest three decades¹. There is a considerable difference between the five Nordic countries in terms of their research activity within this field. Among the 31 studies, fifteen have investigated Norwegian cases, ten have studied Danish cases, four have focused on Swedish contexts, one has investigated Finnish settlements, and one study has compared cities in four Nordic countries (Norway, Denmark, Sweden and Iceland). Table 1 shows, in chronological order, publication reference(s), study area, geographical scale, investigated urban form variables, and main methodological approach of each of these studies. ~~review of literature on the influence of urban form on travel, e~~First, evidence of causality from qualitative research will ~~first~~ be presented (section 5). Thereupon, ~~the status of knowledge about results from research investigating~~ the influence of different aspects of urban form will be reviewed, starting with the neighborhood scale and moving upward in scale via the city/metropolitan level to a regional scale. In section 6, neighborhood-scale density will thus be addressed, followed by local street pattern (section 7), including impacts of residential location at a city/metropolitan scale (section 8), workplace location of workplaces and retail at a city/metropolitan scale (section 9), urban population density at different scales a city scale (section 10), neighborhood design, and the issue of centralization vs. decentralization at different geographical levels a regional scale (section 11). In order to identify the most credible knowledge claims in situations where there are divergent conclusions, emphasis will be laid on criteria such as theoretical plausibility; consistency with qualitative research on rationales for transport behavior; control for relevant non-urban-structural variables as well as for other urban structural variables than the one focused on; non-inclusion of irrelevant control variables; and whether the self-selection issue has been dealt with.

Table 1: Overview of the 31 Nordic studies included in the review

<u>Reference</u>	<u>Study area</u>	<u>Geographical scale²</u>	<u>Urban form variables</u>	<u>Main methodological approach</u>

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			<u>investigated</u>	
<u>Larsen (1982)</u>	<u>Danish urban settlements</u>	<u>Different settlement categories</u>	<u>Regional settlement structure</u>	<u>Multivariate modeling based on empirical input from national travel surveys</u>
<u>Monsen (1983)</u>	<u>Greater Oslo, Norway</u>	<u>Workplace areas within the continuous urban area (pop. 0.9 mill.)</u>	<u>Workplace location</u>	<u>Project-specific travel survey among employees of four companies before and after relocation</u>
<u>Synnes (1990)</u>	<u>Trondheim, Norway</u>	<u>Residential zones within the continuous urban area (pop. 160,000)</u>	<u>Residential location</u>	<u>Comparison of data from local travel survey including approx. 300 individuals living in 15 different residential zones</u>
<u>Hanssen (1993)</u>	<u>Greater Oslo, Norway</u>	<u>Workplace areas within the continuous urban area (pop. 0.9 mill.)</u>	<u>Workplace location</u>	<u>Project-specific travel survey among employees of different branches of a company before and after moving to new, common site</u>
<u>Author (1993)</u>	<u>The 97 largest cities in Sweden and 15 Swedish commuting regions</u>	<u>Continuous urban areas (pop. 10,000 – 1.4 mill.), and commuting regions (defined as areas within 35 km direct distance from the region center)</u>	<u>City-level density, Regional settlement structure</u>	<u>Multivariate analysis based on fuel sales statistics at municipal level and electricity consumption for rail transport</u>
<u>Duun (1994)</u>	<u>Bergen, Norway</u>	<u>Residential areas within the continuous urban area (pop. 220,000)</u>	<u>Residential location</u>	<u>Comparison of regional travel survey data for households living in different residential areas, with households with the highest and lowest income levels excluded</u>
<u>Martamo (1995)</u>	<u>All Finnish municipalities</u>	<u>Municipalities</u>	<u>Residential location, workplace location, regional settlement structure</u>	<u>National census statistics on commuting trip lengths among working residents of each municipality as well as employees of within each 500 by 500 m square of the entire area of Finland</u>
<u>Author, Røe & Larsen (1995)</u>	<u>Greater Oslo, Norway</u>	<u>Residential areas within the continuous urban area (pop. 0.9 mill.)</u>	<u>Residential location, neighborhood density</u>	<u>Multivariate analysis of data from project-specific investigation among 321 households in 30 residential areas</u>
<u>Author & Sandberg (1996)</u>	<u>Greater Oslo, Norway</u>	<u>Workplace areas within the continuous urban area (pop. 0.9 mill.)</u>	<u>Workplace location</u>	<u>Multivariate analysis of project-specific travel survey among 495 employees of 6 companies, and analysis of long-term effects of previous relocations</u>
<u>Author, Sandberg & Røe (1996)</u>	<u>22 cities in four Nordic countries</u>	<u>Continuous urban areas (pop. 8,000 – 1.4 mill.)</u>	<u>City-level density, residential location</u>	<u>Multivariate analysis based on data from oil companies about fuel sales in urban areas, and electricity consumption for rail transport</u>
<u>Hanssen & Fosli (1998)</u>	<u>Greater Oslo, Norway</u>	<u>Two shopping malls; one exurban and one in a suburban local center</u>	<u>Location of shopping</u>	<u>Comparison of shopping trips among approx. 1000 customers at each of 2 shopping malls</u>
<u>Svensson (1998)</u>	<u>Linköping, Sweden</u>	<u>Out-of-town shopping malls and stores within the continuous urban area (pop. 97,000)</u>	<u>Location of shopping</u>	<u>Project-specific travel surveys among individuals (N = approx. 2000) before and after the establishment of three out-of-town shopping malls</u>
<u>Møller & Author (2000)</u>	<u>Aalborg, Denmark</u>	<u>Workplace areas within the continuous urban area (pop. 120,000)</u>	<u>Workplace location</u>	<u>Analysis of project-specific travel survey among employees of 4 schools/public agencies,</u>
<u>Hjorthol (2000a)</u>	<u>Oslo, Norway</u>	<u>Different counties within Oslo Metropolitan Area (pop. 1.2 mill.)</u>	<u>Residential location</u>	<u>Multivariate analysis of data subset from national travel survey (N=791)</u>
<u>Hjorthol (2000b)</u>	<u>Oslo, Norway</u>	<u>A central area, a suburban area and a railway town in the Oslo region (pop. 1.2 mill.)</u>	<u>Residential location</u>	<u>Multivariate analysis of data subset from national travel survey (N=1900), combined with focus group interviews in 3 areas</u>
<u>Hansen & Masud (2001)</u>	<u>Randers, Denmark</u>	<u>Residential areas in the city and surrounding settlements (pop. 60,000)</u>	<u>Residential location</u>	<u>Qualitative interviews and travel registration among 12 households in 4 residential areas</u>
<u>Røe (2001)</u>	<u>Oslo, Norway</u>	<u>Residential areas within the core municipality</u>	<u>Residential location</u>	<u>Qualitative interviews of 15 individuals living in 3 areas, and project-specific travel survey among 400 households in 30</u>

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		(Oslo) (pop. 0.6 mill.)		residential areas
Hartoft Nielsen (2001a)	Copenhagen, Århus and four smaller Danish cities	Residential areas within the metropolitan area/city and surrounding settlements	Residential location	Project-specific travel surveys among residents of new housing areas in each city. Bivariate analyses, but separate analyses for high- and low income respondents
Hartoft-Nielsen (2001b)	Greater Copenhagen and the cities of Århus, Odense and Aalborg, Denmark	Workplace areas within the continuous urban areas (pop. 1.2 mill., 240,000; 160,000 and 120,000, respectively)	Workplace location	Comparison of data from project-specific travel survey among employees of office workplaces differently located
Strømme (2001)	Trondheim, Norway	Workplace areas within the continuous urban area (pop. 160,000)	Workplace location	Comparison of data from project-specific travel survey among employees of 9 differently located workplaces
Tillberg (2001)	Gävle, Sweden	Residential areas in the city and surrounding settlements (pop. 95,000)	Residential location	Qualitative interviews and project-specific travel survey among 83 families with children in 3 residential areas
Nielsen (2002)	Aalborg, Denmark	Residential areas within the city and surrounding settlements (pop. 160,000)	Residential location	Multivariate analysis of project-specific travel survey among 1200 individuals in 23 residential areas, and qualitative interviews of 16 households living at different locations.
Author & Johannsen (2003)	Three previous Danish counties	Intra-county and inter-county comparisons	Regional settlement structure	Multivariate analysis of project-specific travel survey among 969 individual living at different locations in the three countries
Author & Jensen (2002, 2004)	Frederikshavn, Denmark	Residential areas within the city and surrounding settlements (pop. 35,000)	Residential location	Multivariate analysis of project-specific travel survey among 628 individuals in 11 residential areas, and qualitative interviews of 6 households living at different locations
Engebretsen (2005)	The Norwegian cities of Greater Oslo, Bergen and Trondheim, and 4 smaller cities	Census units within the continuous urban areas (pop. 0.9 mill., 220,000 160,000, and 20,000-40,000, respectively)	Residential location	Analysis of data from national and regional travel surveys of a total of 55,000 respondents living in different census units.
Holden & Norland (2004)	Oslo, Norway	Residential areas within the continuous urban area (pop. 0.9 mill.)	Residential location, neighborhood density	Multivariate analysis of project-specific travel survey among 941 individuals in 8 residential areas
Author (2005, 2006a, 2006b, 2009 and 2011)	Copenhagen Metropolitan Area, Denmark	Residential areas within the metropolitan area (pop. 1.8 mill.)	Residential location, neighborhood density, street pattern, regional settlement structure	Qualitative interviews of 17 households living at different locations, multivariate analysis of project-specific travel survey among 1932 individuals in 29 residential areas, and analysis of travel diary investigation among 273 of those.
Tennøy & Lowry (2008)	Oslo, Norway	Workplace areas within the core municipality (Oslo) (pop. 0.6 mill.)	Workplace location	Project-specific travel survey among employees of different companies before and after moving to new, common site
Westford (2010)	Stockholm, Sweden	Neighborhoods in the suburb of Täby with different street patterns	Street pattern	Multivariate analysis of data from project-specific travel survey among 449 residents in four neighborhoods about their children's trips to school
Engebretsen, Hanssen & Strand (2010)	Norwegian cities within different size categories (aggregate data)	Residents living at different locations within cities and surrounding areas	Residential location, location of shopping, neighborhood density	Analysis of data from national and regional travel surveys of shopping trips among 17,500 respondents living at different locations
Author, Silva & Pinho (2011)	Greater Copenhagen, Denmark (compared to Greater Oporto,	Residential areas within the continuous urban area (pop. 1.2 mill.)	Residential location, neighborhood density	Multivariate analysis of project-specific travel survey among 1116 individuals in 18 residential areas in Greater Copenhagen.

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2.5 Causality and transport rationales

In order to substantiate that residential location is a (contributory) cause of differences in travel behavior, the basic mechanisms by which residential location influences travel behavior must be identified. Examples showing the *rationales* on which people base their frequency of participation in out-of-home activities, the locations of these activities, the modes of travel used to reach these locations, and the routes followed make up important links in the mechanisms by which urban structures influence travel behavior. Transport rationales are here understood as the backgrounds, motivations and justifications that agents draw on when they make transport-relevant decisions about their participation in activities, location of these activities, modes of transportation and the routes followed (see Author & Jensen, 2005, p. 165). The concept, which includes instrumental, safety-based, comfort-based, aesthetic as well as affective dimensions, has some overlap with the notion of ‘mobility view’ coined by Beckmann (2001). Combined with the spatial configuration of residences, employment and other facilities in a city or metropolitan area, the transport rationales produce some characteristic relationships between residential location and travel found in a number of different urban contexts (see below).

Internationally, relatively few studies have ~~Only a few studies have~~ included qualitative interviews in order to identify such rationales, reflecting a general dominance of quantitative research within the field of land use and transport studies. However, among the few qualitative investigations of transport rationales, a high proportion has been carried out in a Nordic context (Røe, 2001; Tillberg, 2001; Nielsen, 2002; Author & Jensen, 2002, 2004 and 2005; Author, 2005, 2006a; Næss, 2009a; see also Næss & Jensen, 2005). These studies have been carried out in ~~very~~ different urban contexts: the metropolitan areas of Oslo in Norway and Copenhagen in Denmark ~~Denmark (with 1.8 million inhabitants, of which 1.2 million in the continuous urban area), the medium-sized towns of Aalborg (Denmark) and Gävle (Sweden), and and Hangzhou in China (with 4 million inhabitants, of which 2 million in the continuous urban area)~~ the small town of Frederikshavn in Denmark. Nevertheless, the rationales identified in the ~~two~~ different urban regions are highly similar ~~consistent~~.

Based on interviews with 15 individuals living in three different locations in Oslo (the inner city, a suburb along an urban rail line, and a low-density area with poor public transport access), Røe (2001) characterizes the mobility lifestyle of most of his interviewees as ‘late-modern’ and spatially flexible. Typical for this mobility lifestyle is that proximity is of minor importance when choosing where to live, work and carry out leisure activities. The social networks are also spread over a large area, sometimes including exurban areas. Some of his interviewees still have less mobility resources and their mobility lifestyle (characterized by Røe as ‘high-modern’) is therefore less flexible, based to a high extent on public transportation. However, for both mobility lifestyle groups, residential location has a bearing on travel behavior. For the highly flexible individuals, residential location in the inner city with many facilities in the proximity of the dwelling allows choice between a large number of services in the vicinity of the dwelling as well as elsewhere in the urban region, whereas people belonging to the same mobility lifestyle group and living at the outskirts of the city need to travel long distances in order to meet their preferences. For inner-city residents with less flexible mobility lifestyles, availability of a wide range and number of facilities within a relatively short distance from the dwelling allows high opportunities for choice despite these interviewees’

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relatively confined geographical radius of action. Members of the low-mobility lifestyle group living in the suburbs are, however, experiencing several spatial constraints and a low degree of freedom of choice, especially if the area is poorly served by public transportation. (Røe, 2001, p. 221.)

In her study of activity participation and travel behavior among families with children in the Swedish city of Gävle and its surroundings, Tillberg (2001) found that chauffeuring to children's organized leisure activities often dominated the household's time schedule after work. The rural children were engaged in urban-based activities to the same extent as the children living close to the city center. Although the rural parents had often motivated their move to a peripheral settlement by the assumed favorable conditions for children's play in such areas, rural children often spent less time than the inner-city children in their home milieu, due to their extensive and time-consuming travel to organized leisure activities.

Based on interviews among households in Aalborg, Nielsen (2002) finds that the location of especially jobs and leisure activities is usually chosen within the entire urban area (as distinct from within the local neighborhood). The same is partly also true for social contacts, although people who have recently moved to the city (and thus have not yet developed a wide social network) and parents of children may to a higher extent maintain social contacts within the local neighborhood. Grocery shopping is an example of an activity more often taking place locally (if possible), yet many people may prefer to do shopping in a larger store on the way home from work. For the activities where locations are chosen within a wider area, mean trip distances among the residents of a neighborhood depend on where the chosen facilities are on average located. Due to the concentration of jobs, stores and leisure opportunities in certain districts, the interviewees' amount of daily-life travel was to a high extent influenced by the distance from the dwelling to the city center and a second-order center.

All the above-mentioned studies highlight the fact that people do not necessarily use the closest ones among available facilities. The implications of this to the relationships between residential location and travel are elaborated on in the studies by Author and Jensen in Copenhagen Metropolitan Area and the small town of Frederikshavn and its surroundings (Author & Jensen, 2002, 2004 and 2005; Author, 2005, 2006a). The rationales identified among the Copenhagen and Hangzhou interviewees, and the mechanisms by which urban structure influences their travel, are strongly consistent with the relationships between residential location and travel found in the quantitative parts of the Copenhagen and Hangzhou studies as well as in a number of other cities. This qualitative material, based on 17 in-depth interviews in the Copenhagen case and 28 in the Hangzhou case, can therefore help to explain such aggregate level patterns.

Both among the Copenhagen and the Hangzhou-Frederikshavn interviewees, *leisure activity patterns* are to some extent adapted to the availability of facilities in the proximity of the dwelling. The interviewees still rarely give up activities completely as a result of moving to a different urban structural situation. 'Distance decay' in the form of reduced *activity participation* when living far away from relevant facilities ~~is was~~ not very pronounced among the interviewees. For workforce participation, there ~~is was~~ hardly any tendency at all among the ~~Copenhagen and Hangzhou~~ interviewees (nor among the survey respondents ~~of the two studies~~) of reduced participation when living far away from employment concentrations, ~~and hardly any tendency among suburbanites of more frequent home-based 'teleworking' than among their inner-city counterparts. There was still a tendency among suburban women of confining their choices on the labor market to a smaller geographical area than that of their male counterparts. There was also hardly any tendency among~~

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~~suburbanites of more frequent home-based 'teleworking' than among their inner-city counterparts.~~

The modest occurrence of 'distance decay' implies that long distances to workplaces and other facilities are only to a very limited extent compensated through reduced employment or participation in leisure activities.

~~In both Hangzhou Metropolitan Area and Copenhagen Metropolitan Area,~~ The interviewees' choices of *locations for their activities* (work, shopping, leisure etc.) ~~are-were~~ based on a balancing between a wish to minimize traveling distances and/or travel time, and a wish for choosing the best and most suitable facility. What is considered the best facility does not only involve a judgment of where the instrumental purpose of the activities can best be met, but can also include how well the facilities match one's cultural, aesthetic and symbolic preferences, how suitable they are as meeting points for social contacts, or simply variety-seeking.

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A high emphasis on minimizing the friction of distance ~~implies-means~~ that less-than-ideal facilities are accepted if facilities of the desired quality are not available within a low threshold for acceptable travelling distance. On the other hand, a high emphasis on choosing the best facility ~~implies-means~~ that relatively long travelling distances are accepted if necessary to access a facility of the sought-for quality. Circumstances contributing to a high priority attached to the rationale of choosing the best facility, compared to distance minimizing include: specialized job skills, specialized leisure interests and 'exclusive' cultural taste, much time available, high mobility resources, many facilities available in the local area of the dwelling, and short distance from the local facilities to the closest competing concentration of facilities.

For most travel purposes, the Copenhagen ~~and Hangzhou Metropolitan Area~~ interviewees emphasized the possibility to choose among facilities rather than proximity. This means that their amount of travel was influenced to a higher extent by the location of the residence in relation to concentrations of facilities, rather than the distance to the closest single facility within a category³. In particular, this was the case for workplaces and places of higher education, but also for cultural and entertainment facilities, specialized stores and, to some extent, also grocery stores. As a result of this, combined with the actual spatial configuration of workplaces, service and leisure facilities, the amount of ~~(car)~~ travel was in particular influenced by the location of the dwelling relative to the main center of each metropolitan area, and only to a lesser extent by its location relative to lower-order centers. For leisure activities, the "atmosphere" and the aesthetic qualities at the destination also played a role, contributing to strengthen the attraction of the central parts of ~~Copenhagen and Hangzhou~~ the city.

The ~~Copenhagen and Hangzhou~~ interviewees' choices of *travel modes* ~~are-were~~ influenced by two main groups of rationales concerning, respectively, the efficiency of the movement from origin to destination, and the process of moving from origin to destination. The first of these two groups includes concerns related to the time consumption, economic costs and accessibility benefits of travelling by different modes. The second group includes concerns related to physically, psychologically and socially positive or negative aspects associated with travelling by a particular mode. Several of the rationales ~~are-were~~ hinted at indirectly through a criterion of trip distance as an important condition through which more basic rationales such as time saving or limitation of physical efforts influence modal choices. Since long trips will be very time-consuming as well as physically exhausting if they are made by non-motorized modes (in particular by foot), rationales of time-saving and limitation of physical efforts logically imply that travel modes depend on trip distances. Living close to relevant trip destinations thus contributes not only to shorter travelling

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distances, but also implies a higher propensity of using non-motorized modes. For similar reasons, walking distance to public transport stops influences on people's propensity of using these modes.

The emphasis attached by the interviewees on the mode choice rationales appears to be influenced by a number of individual and contextual conditions, including the interviewees' mobility resources, social obligations, time-geographical constraints, and the purpose of the trip.

The rationales identified for route choice in the Copenhagen study imply that the interviewees are not apt to make long detours from the shortest route to daily-life destinations. These rationales thus support, in line with the so-called activity-based approach to transport research (Jones, 1990), the assumption that daily-life travel is mainly an activity derived from the need or wish to carry out other, stationary activities.

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6. Neighborhood-scale density

Internationally recent years, most studies of relationships between urban density and travel have focused on the neighborhood scale instead of the city as a whole (see, e.g., Handy & Clifton, 2001; Chatman, 2005; Rajamani et al., 2003; Handy et al., 2005; Boarnet & Crane, 2001). For example, the density component of 'the three D's' (density, design and diversity) coined by Certero and Knockelman (1997) as key urban form characteristics influencing travel referred mainly – implicitly or explicitly – to the local urban neighborhood or district. In the Nordic countries, local-scale density has not to the same extent been at the center of interest. Local area density has still been included in several studies together with variables indicating the location of dwellings, jobs or stores (Table 2).

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In a study of residential areas in Oslo, Author, Larsen & Røe (1995) found an influence of high local area density in terms of a higher proportion of travel by public transport. Local-area density did not, however, show any effect on overall traveling distances. In Copenhagen Metropolitan Area, Author (2011) found a slight tendency of increased traveling distance by car when living in a low-density local area, yet no identifiable effect was found on neither modal split nor overall travel distance. In another study in Greater Oslo, no effect of local-area density was found (Holden & Norland, 2004). The same applies to study in the small Danish town of Frederikshavn (Author & Jensen, 2004). It should be noted that in all these studies, clear correlations were found between local-area density and most travel behavior variables when controlling for only demographic and socioeconomic variables but not for the location of the dwelling relative to the city center. Once the latter variable was included in the analysis, the effects of local-area density vanished or were substantially weakened.

In a comparison of six workplaces in Greater Oslo, Author & Sandberg (1996) found a clear effect of local-area density on the modal split of journeys to work, with higher shares of car commuting and lower shares of travel by transit among employees of workplaces located in high-density areas. This effect persisted also when controlling for the location of the workplace relative to the city center. The population density in the areas around shopping malls has also been found to influence the amount of car travel for shopping trips, measured in vehicle kilometers as well as in the modal split between car and other modes (Hansen & Fosli, 1998; Engebretsen, Hanssen & Strand, 2010). This mainly reflects very high levels of car driving to exurban shopping malls.

The relatively modest influences of the density of residential neighborhoods found in the above-mentioned studies squares well with the findings in Although many studies have found correlations between density measured at this level and travel behavior, these correlations are most considerably weakened or even vanish once control is made for the location of the neighborhood relative to the city center (see, e.g., Naess, 2011). In Ewing and Cervero's (2010) international meta-analysis, too, where only small elasticities were found between vehicle miles traveled and, respectively, population and job densities. Compared to Ewing and Cervero's meta-analysis, the Nordic studies do, however, show stronger effects of the density in the local areas around workplaces and stores.

This should, however, not lead us to conclusion that a high local area density contributes only weakly to reduce car traffic and emissions from transport. Local area densities add up to the overall density of the city, which has, as shown above, considerable influence on travel behavior. High local area density also strengthens the population base for local service facilities and thus increases the likelihood that such destinations can be found within walking distance. Several empirical studies have, in line with this, concluded that higher residential densities do promote higher shares of non-motorized trips in connection with non-work activities (Handy & Clifton, 2001; Rajamani et al., 2003; Handy et al., 2005; Naess, 2006a). Such an increase in the share of local walking (or biking) trips is important from a public health perspective (Frank et al., 2004; Ewing et al., 2006), although the travel mode for these short trips does not in itself exert much influence on the overall number of vehicle kilometers traveled. However, if availability of local shops and other services within walking distance makes some residents choose these facilities instead of driving to facilities outside the local neighborhood, the overall amount of motorized can be reduced to a higher extent. A study in the Central Puget Sound in USA thus found evidence of a fairly high reduction in vehicle miles traveled attributable to higher accessibility of facilities within the neighborhood, where neighborhood accessibility was measured as an index combining density, land use mix, and street patterns (Krizek, 2003).

Table 2: Nordic studies investigating the influence of neighborhood-scale density on travel behavior

Reference	Main influential urban form variables (any standardized regression coefficients, in parenthesis)	Main categories of control variables	Addressing the 'self-selection problem'?	Car ownership as control variable?	Main argument
Author, Røe & Larsen (1995)	Density of dwellings in the residential area (=0.179***) (Proportion of travel by public transport)	Demographics and socioeconomics, and also distance to the city center and level of public transit service	No	Yes	High density of dwellings in the residential area contributes to a high proportion of travel by public transport
Author & Sandberg (1996)	Density in the local area of the workplace (-0.282***) (Proportion of car commuting)	Demographics and socioeconomics	Not relevant	Yes	Workplace location in high-density areas of Oslo contributes to lower share of car commuting and higher share of commuting by public transport.
Hanssen & Fosli (1998)	Density in the local area of the shopping center	None	Not relevant	No	Location of a shopping mall in a relatively dense suburban center in the outskirts of Greater Oslo contributes to lower share of car trips and less vehicle km by car per customer than location in a low-density exurban part of the urban region.
Author & Jensen (2002, 2004)		Demographics, socioeconomics, transport attitudes and leisure interests	Partly	Yes	No separate effect found of local-area density when controlling for the distance to the city center
Holden & Norland (2004)		Demographics, socioeconomics, environmental attitudes, transit period card, location of the residential area	No	Yes	No separate effect found of local-area density when controlling for the distance to the city center
Engebretsen, Hanssen & Strand (2010)	Population density in the local area around shopping centers	None	Not relevant	No	Lower amount of car travel for shopping trips to shopping malls in or close to Norwegian cities above 50,000 inhabitants with a high population density in the local area of the center
Author (2011, 2005, 2006a, 2006b, 2009)	Population and job density in the local area of the residence (0.093) (Travel distance by car on weekdays)	Demographics, socioeconomics, residential preferences, distances to city center, second-order center and to urban rail station	Yes	Included as well as not included ⁵	Living in a low-density local area contributes to longer traveling distance by car on weekdays

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7. Local street pattern

Compared to a considerable focus on neighborhood-scale street pattern in American studies, the impact of street design on travel modes or distances has only been addressed in a very few Nordic studies (Table 3). In one of these few studies the relationship between the local-level street structure on traveling distance by car disappeared as soon as control was made for the location of the residence relative to the metropolitan center (Author, 2011). In another study, Westford (2010) found somewhat lower propensity for children living in a single-family home area with grid street pattern and mixed traffic to walk to school, and a corresponding tendency of more frequent chauffeuring by car, than in three adjacent neighborhoods with separate roads for motorized and

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non-motorized traffic. This tendency of higher shares of car travel in neighborhoods with grid-shaped street pattern is the opposite of what has been concluded in several American studies.

Table 3: Nordic studies investigating the influence of neighborhood-scale street pattern on travel behavior

Reference	Main influential urban form variables (any standardized regression coefficients ⁶ in parenthesis)	Main categories of control variables	Addressing the 'self-selection problem'?	Car owner-ship as control variable?	Main argument
Westford (2010)	Local street pattern*** (Traveling by foot to school)	Demographics, socioeconomics	No	No	Lower propensity for children to walk to school in a single-family home area with grid street pattern and mixed traffic than in three adjacent neighborhoods with separate roads for motorized and non-motorized traffic
Author (2011)	Local street pattern (-0.004) (Travel distance by car on weekdays)	Demographics, socioeconomics, residential preferences, distance to city center	Yes	No	No effect found of local street pattern (grid structure or other street pattern) on travel behavior variables once control is made for distance to the city center and demographic, socioeconomic and attitudinal variables

4.8 Residential location at a city/metropolitan scale location and travel behavior

The aspect of urban form that has attracted the greatest amount of research on its impacts of travel behavior in the Nordic countries is the location, density and design of residential areas. In this section the attention will be directed toward the location of dwellings at a city/metropolitan scale in relation to the city center and other major concentrations of employment and regional service. This aspect has been addressed in 19 of the 31 Nordic studies included in the review (Table 4).

To some extent, the impacts of residential location relative to the metropolitan center structure will be compared to the influences of the type of local built environment in which the dwelling is located. The latter, local neighborhood characteristics will, however, mainly be dealt with in sections 7 (Density) and 8 (Neighborhood design).

In the United States, research has to a high extent focused on the influence of local residential neighborhood characteristics on travel behavior, comparing traditional suburban residential areas with areas developed according to the so-called 'New Urbanism' or 'Transit Oriented Development' principles (e.g., Boarnet & Crane, 2001; Cervero, 2003; Krizek, 2003). Among 38 research studies included in a recent American review article (Cao et al., 2009), only 6 addressed the location of the neighborhood relative to the city center or other major concentrations of facilities. In contrast, the primary field of interest of European research has been directed towards the location of the residence relative to the main metropolitan center and sub-centers within the metropolitan-scale spatial structure.

Available evidence indicates that the latter aspects of residential location are more influential than neighborhood attributes on travel behavior. In Ewing and Cervero's (2010) above-mentioned meta-analysis, the two variables indicating the distance from the residence to main concentrations of facilities ('job accessibility by auto' and the distance to downtown) were the ones showing the strongest effects on the number of vehicle miles traveled. The impacts of street design and local job density was found to be lower. Ewing and Cervero's meta-analysis does not include information

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about whether or not other urban structural variables than the ones highlighted in the various studies have been controlled for. However, given the dominance of American studies in their meta-analysis and the fact that most American studies have only included local-scale variables (cf. above), the stronger impact of metropolitan-scale than neighborhood-scale variables on the amount of car travel is worth noticing. As argued by Næss (2006 and 2011), the lack of inclusion of variables indicating the location of neighborhoods in relation to the metropolitan-scale center gives rise to suspicion that the relationships found in several American studies between the local-level street structure and other local neighborhood design variables on traveling distances might perhaps reflect the location of the residential areas rather than the shape of the local street network.

In Ewing and Cervero's meta-analysis, street intersection density and street connectivity was found to be almost as influential as distance to downtown or employment concentrations on the number of vehicle kilometers traveled. However, based on the transport rationales discussed in the previous section, it is difficult to justify why local-area street design would exert any strong influence on overall traveling distances by car. Instead, the location of the residence relative to main concentrations of facilities (in particular employment) could be expected to exert far stronger influence on traveling distances in general and car travel in particular. This is also what has been found in a number of studies in countries other than USA. Investigations in a number of European, and also some Asian and American/Nordic cities and metropolitan areas have shown that those living in the outer parts travel considerably longer by motorized means of transportation, compared to the residents of inner and central parts of the town. The same main pattern has been found in cities as different as Paris (Mogridge 1985, Fouchier 1998), London (Mogridge, *ibid.*), New York and Melbourne (Newman and Kenworthy 1989), San Francisco (Schipper et al. 1994), Austin, Texas (Zhou & Koekelman, 2008); Greater Copenhagen (Hartoft-Nielsen 2001a, Author 2006a and b, 2009, 2011), Greater Oslo (Author, Røe & Larsen 1995; Røe 2001), Helsinki (Lahti-Martamo, 1995), Århus (Hartoft-Nielsen, *ibid.*), Bergen (Duun, 1994), Trondheim (Synnes, 1990), Gävle and its surroundings (Tillberg, 2001), four medium-sized Danish provincial cities (Hartoft-Nielsen, *ibid.*), and Frederikshavn (Author & Jensen, 2002 and 2004); Hangzhou (Næss, 2009b and 2010) and Santiago de Chile (Zegras, 2010). In some of these studies, the influences of residential location on trips with different purposes have been analyzed separately. A large proportion of the differential between suburbanites and inner-city dwellers in traveling distances has been found to be attributable to differences in commuting distances (Hartoft-Nielsen, 2001a; Author, 2006c, 2007b and 2009b). However, residential location close to the concentration of facilities in the inner city has also been found to contribute to shorter non-work trips (Krizek, 2003; Author, 2006c).

In an article specifically comparing the influence on metropolitan-scale and neighborhood-scale urban form characteristics in Copenhagen Metropolitan Area, on traveling distances by car, Author (2006a, (2011) found the impacts of metropolitan-scale urban structural variables, in particular the distance from the dwelling to the city center, to be considerably more influential than neighborhood-scale characteristics. Some local-scale variables often mentioned in the literature as influential, such as the street pattern in the neighborhood, showed no significant effect on car travel once control was made for the location of the dwelling relative to the city center. The distance from the residence to the closest second- and third-order centers and local area density were, however, found to influence travel distances by car as well as the modal shares to some extent. In Aalborg, Nielsen (2002) found the distance to the city center to be the main urban form variable influencing traveling distances, but proximity to a second-order center at the southern fringe of the city also contributed to some reduction in the distance traveled. Similar results were have been found also in Greater Oslo, where, apart from the effect of living close to the city center, proximity to service facilities contributed to a certain decrease in weekly traveling distances and high local

~~area density to a higher share of public transport (Author, Røe & Larsen, 1995; Røe, 2001; Holden & Norland, 2004).~~

As mentioned in section 3, self-selection of residents into geographical locations matching their traveling preferences has been mentioned as a source of error precluding researchers from drawing firm conclusions about influences of residential location on travel. ~~In particular, this has been a topic of debate among American researchers, but increasingly also in the European academic discourse.~~ In 2009, the 'self-selection problem' was thus the subject of a special issue of the journal *Transport Reviews*. In one of the articles of this special issue, ~~Cao et al. (2009) reviewed 38 studies (mostly North American) explicitly addressing the extent to which associations between the built environment and travel behavior could be explained by attitude-based residential self-selection. Cao et al. concluded that a statistically significant influence of the built environment remained after self-selection was accounted for in virtually all the studies included in their review. However, the influence of the built environment diminished substantially once residential self-selection was taken into account. It should be noted here that only a few of the studies reviewed by Cao et al. included the distance from the dwelling to downtown or other regional-scale concentrations of facilities. In another article in the same special issue,~~ Author (2009~~ab~~) takes a different view on the issues of self-selection than conventionally construed in the literature. According to Author, the fact that people to some extent 'self-select' into areas matching their transport attitudes (and car ownership) is in itself a demonstration of the importance of urban structure to travel behavior. If there were no such influence, people who prefer to travel by non-motorized modes might as well settle in the peripheral part of the metropolitan area, far away from public transport stops and the concentration of workplaces and service facilities found in the central and inner city. Anyway, empirical evidence from Copenhagen Metropolitan Area shows a considerable influence of residential location (in particular the distance from the dwelling to downtown) on traveling distances by car also after controlling for residential self-selection. (Author, 2009~~ab~~).

~~Similar results were found in a subsequent study of Hangzhou Metropolitan Area (cf. section 4), where energy use for transport was found—after controlling for residential self-selection and socio-demographic variables—to be four times as high among respondents living more than 10 km from the city center as among their inner-city counterparts (Næss, 2010).~~

~~As mentioned above, a problem when calculating average elasticities between residential location and travel is the fact that the number of control variables differs across studies (Zegras, 2010). In Ewing & Cervero's (2010) meta-analysis, studies addressing residential self-selection were explicitly identified, but the studies included in their meta-analysis also differed in terms of their inclusion of urban structural as well as other control variables. For example, m~~Many studies – in the Nordic countries as well as internationally – of residential location and travel include car ownership as a control variable, and some also control for attitudes to car travel. However, car ownership and transport attitudes are themselves subjects to influence from residential location: by providing oneself with a car (or possibly a second car), long distances to trip destinations can be compensated through higher travel speeds, and more time will be available for other everyday activities (Hägerstrand, 1970).

If the purpose of the analysis is to identify and estimate the magnitude of the influence of residential location on travel, the inclusion of control variables that are related to the location of the dwelling with two-way causality leads to an underestimation of the effect of residential location (unless the indirect effects of residential location via these variables are simultaneously taken into consideration). As demonstrated by Author (2009b), the influence of residential location on car

ownership among Copenhagen Metropolitan Area respondents was considerable and probably at least as strong as the influence of car ownership on residential location. Information from qualitative interviews with persons who had moved from one residential address to another address within the metropolitan area underpinned this statistical relationship. Moreover, questionnaire survey analyses of movers showed a tendency of somewhat increased car ownership as a result of moving to a more peripheral part of Copenhagen Metropolitan Area. Outer-area respondents also felt much more dependent on car travel to reach daily destinations than their inner-city counterparts (ibid.). Clear effects of residential location on car ownership were also found in studies of the little Danish town of Frederikshavn (Næss & Jensen, 2004), in Hangzhou Metropolitan Area (Næss, 2007a), as well as in Santiago de Chile (Zegras, 2010). Qualitative interviews carried out by Nielsen (2002) in Aalborg and by Røe (2002) in Oslo also illustrate the mechanisms through which moving from an inner-city to a suburban housing estate may induce people to acquire a (second) car. Clear effects of residential location on car ownership were also found in a study of the little Danish town of Frederikshavn (Author & Jensen, 2002 and 2004).

Similarly, attitudes to car travel can influence residential location but may also be influenced by the location of the dwelling. In much of the literature on self-selection, the latter influence has been ignored. However, inner-city residents traveling mainly by public or non-motorized modes while being exposed to nuisances from traffic originating mostly in the suburbs are likely to develop less car-friendly attitudes than suburbanites who feel the car as a necessity in order to reach their daily activities (Bagley & Mokhtarian, 2002; (Author, 2009ab) – a point also emphasized by Bagley & Mokhtarian (2002).

Given the at least equally strong effects of residential location on car ownership and attitudes as the opposite influences found in his studies, Author (2009ab) recommended that only socioeconomic and demographic variables and transport-related residential preferences should be included as control variables, while car ownership and attitudes to car travel should both be excluded. Based on such a set of control variables, he found traveling distances by car among residents of the most peripheral parts of Copenhagen Metropolitan Area to be on average nearly four times as long as among residents living close to the city center. A very similar center-periphery gradient was also found in a previous study of Copenhagen Metropolitan Area including only income as control variable (Hartoft-Nielsen, 2001a).

Table 4: Nordic studies investigating the influence of residential location at a city/metropolitan scale on travel behavior

<i>Reference</i>	<i>Main influential urban form variables (any standardized regression coefficients' in parenthesis)</i>	<i>Main categories of control variables</i>	<i>Addressing the 'self-selection problem'?</i>	<i>Car ownership as control variable?</i>	<i>Main argument</i>
<u>Synnes (1990)</u>	<u>Distance to city center</u>	<u>None</u>	<u>No</u>	<u>No</u>	<u>Longer commuting distances and total traveling distance among persons living far away from the city center of Trondheim</u>
<u>Duun (1994)</u>	<u>Distance to city center</u>	<u>Some control for income, otherwise none</u>	<u>No</u>	<u>No</u>	<u>Longer mean traveling distance among households living far away from the city center of Bergen</u>
<u>Lahti (1995)</u>	<u>Distance to city center</u>	<u>None</u>	<u>No</u>	<u>No</u>	<u>Longer mean commuting distance among workforce participants living far away from the city center of Helsinki</u>
<u>Author, Røe &</u>	<u>Distance to city</u>	<u>Demographics and</u>	<u>No</u>	<u>Yes</u>	<u>Longer weekly motorized traveling distances</u>

Larsen (1995)	center (0.472***) Mean distance to local service facilities (0.158**) (Motorized travel distance)	socioeconomics, and also local area density and level of public transit service				(and also higher energy use) among residents living far away from the city center of Oslo. Also somewhat longer motorized traveling distances the further away the dwelling is located from local service facilities
Martamo (1995)	Distance to the city center	No	Not relevant	No		Inhabitants of the outer parts of Helsinki metropolitan areas and the other largest Finnish urban regions have longer commuting distances than inhabitants of areas closer to the city centers.
Author, Sandberg & Røe (1996)	The degree of concentration of the urban population towards the city center (0.363*) (Energy use for transport)	Population size, composition of trades, income, other socioeconomics, exurban commuting, and overall population density	Not relevant	Yes		For towns with similar population size and overall population density, energy use for transportation tends to be lower, the shorter is the average distance from dwellings to downtown
Hjorthol (2000a)	The part of the region in which the dwelling is located ***	Demographics and socioeconomics	No	Yes		Longer commuting distances among residents of the outer parts of the Oslo region than in the inner-city of Oslo
Hjorthol (2000b)	The part of the region in which the dwelling is located ***	Demographics and socioeconomics	No	Yes		Higher share of car trips among residents of the outer parts of the Oslo region than in the inner-city of Oslo
Tillberg (2001)	The part of the municipality in which the dwelling is located	None	No	No		Longer weekly total traveling distances and travel distances by car among residents of outer parts of Gävle than among inner-city residents, and by residents of a rural village than in a small peripheral urban settlement
Hansen & Masud (2001)	Distance to the city center	Not relevant	No	No		For daily-life routine trips, families with children in the outer parts of the municipality of Randers tend to travel longer distances, especially by car, than their inner-city counterparts. For non-routine leisure trips, no clear difference is found.
Hartoft Nielsen (2001a)	Distance to the city center	Separate bivariate analyses for respondent groups according to income, gender, driver's license holding and car ownership	No	Yes		Living far away from the main city center of Copenhagen is associated with longer overall traveling distances as well as by car, shorter traveling distances by non-motorized modes, longer commuting distances, higher share of car travel and lower non-motorized share. Living peripherally is also associated somewhat longer weekend travel. Similar effects in the Danish provincial city of Århus, and (albeit weaker) in the 4 medium-sized provincial cities.
Røe (2001)	Distance to city center (0.254**) Distance to private service facilities (0.170)*	Demographics and socioeconomics. But also controlling for commuting distance, which is hardly relevant.	No	Yes		Longer traveling distances, more frequent car trips and less frequent non-motorized trips among residents of outer suburbs than in Oslo's inner city. Living far away from city center and, to some extent, private service, contributes to longer overall travel distances.
Nielsen (2002)	Distance to city center (0.202***) Distance to second-order suburban center (0.097***)	Demographics and socioeconomics, plus leisure interests and place of adolescence	No	Included ^a as well as not included		Longer total traveling distances, as well as by car and by public transport, among residents living far away from the main city center of Aalborg as well as from the suburban second-order center. Residential location also influences car ownership
Author & Jensen (2002, 2004)	Distance to city center (0.240***)	Demographics, socioeconomics, transport attitudes and leisure interests	Partly	Yes		Living close to the city center of Frederikshavn contributes to shorter overall traveling distances, higher share of non-motorized travel and lower share of travel by car. Residential location also influences car ownership
Engebreetsen (2005)	Distance to city center	None	No	No		Overall weekly traveling distance as well as the proportion traveled by car increases with increasing distance from the dwelling to the city centers of Oslo, Bergen and Trondheim,

					respectively
Holden & Norland (2004)	Distance to city center (0.213**) Distance to closest local center (0.100*) (Energy use for everyday transport)	Demographics, socioeconomics, environmental attitudes, transit period card, local area density	No	Yes	Higher energy use for everyday transport the further away the respondents live from the main city center of Oslo, and to some extent also the further they live from the closest local center
Author (2005, 2006a, 2006b, 2009 and 2011)	Distance to city center (0.145***) Distance to closest second-order center (0.055) Distance to closest urban rail station (0.046) (Total travel distance on weekdays)	Demographics, socioeconomics, transport attitudes, environmental attitudes, residential preferences, local area density	Yes	Included ⁹ as well as not included	Living far away from the main city center of Copenhagen contributes to longer overall traveling distances as well as by car and by public transport, shorter traveling distances by non-motorized modes, longer commuting distances, higher shares of car travel and lower non-motorized share. Living peripherally also contributes to somewhat longer weekend travel. Residential location also influences car ownership
Engebretsen, Hanssen & Strand (2010)	Distance to city center (Modal split for shopping trips)	None	No	No	Higher share of non-motorized shopping trips among those residents of Norwegian cities above 50,000 inhabitants who live close to the centers of their respective cities
Author, Silva & Pinho (2011)	Distance to the main city center (0.127**) Distance to the closest main regional retail center (0.079*)	Demographics, socioeconomics, distance to closest second-order center	No	No	Among residents of the continuous urban area of Copenhagen, living far away from the city center contributes to longer overall travel distances, higher share of car travel, and lower share of non-motorized travel. Travel distances are also increased if living far from closest main regional retail center and the share of car travel if living far from the closest second-order center

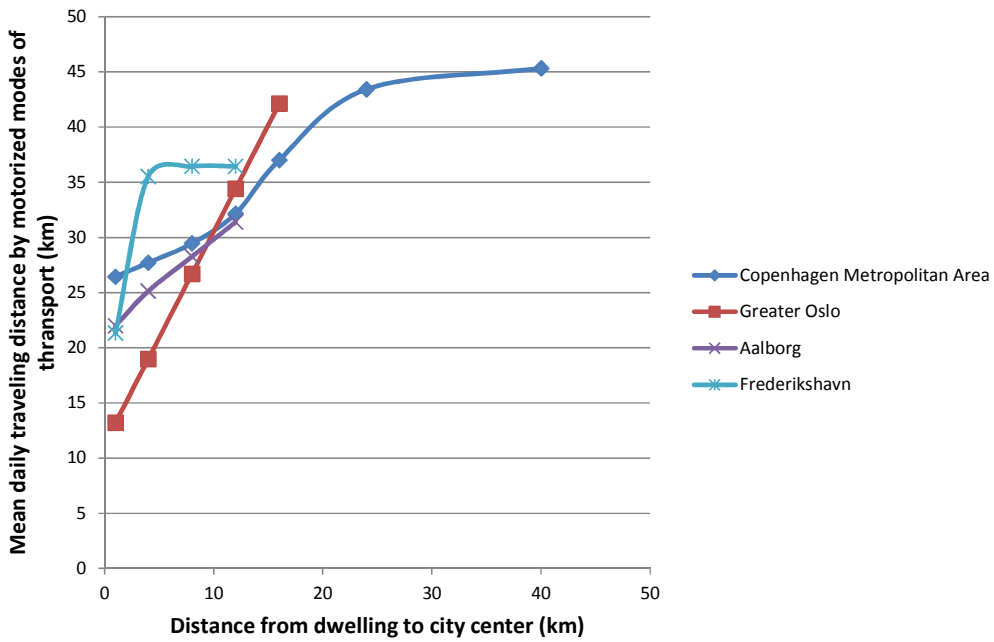
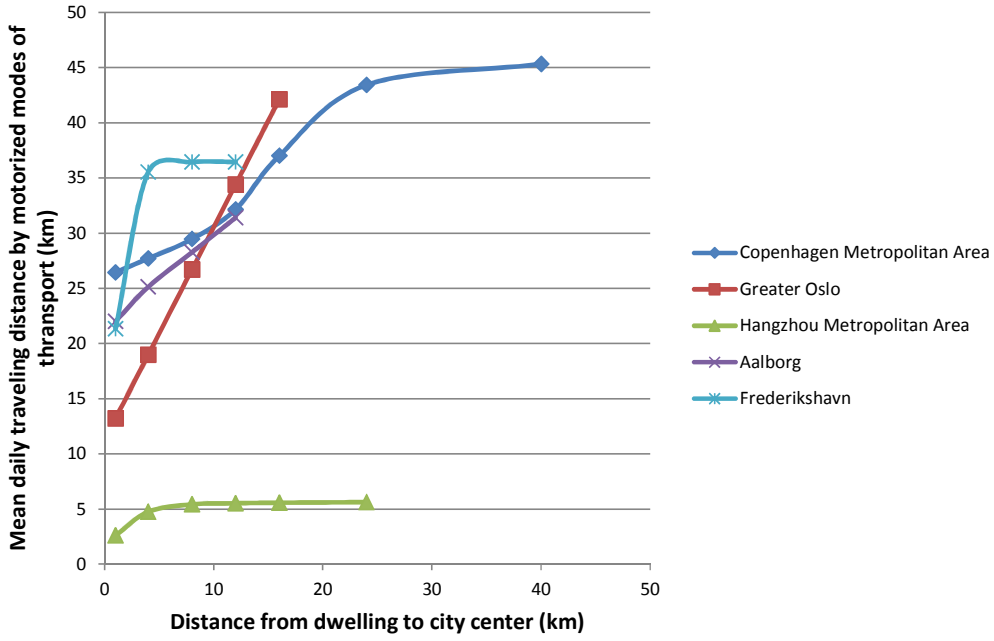
In Ewing & Cervero's (2010) meta-analysis, average elasticities for associations between built environmental characteristics and aspects of travel behavior found in the various studies were calculated as the ratio of the percentage change in one variable associated with the percentage change in another variable. In the present review, strengths of relationships have been indicated (where available) by standardized regression coefficients, but we have not calculated averages across studies. However, since the relationships between residential location and travel are not necessarily linear (this depends, among others, on how widely the investigated area has been demarcated), elasticities for relationships between residential location and travel may be different in different parts of a city or a metropolitan area. Generally, the change in a travel behavior variable resulting from a given change in the distance to the city center will be smaller if the distance to the city center is at the outset long than if the first location is in the inner parts of the city. Moreover, the change in traveling distance resulting from a one-km increase in the distance between the city center and the dwelling is smaller in big cities than in small towns, where built environment characteristics may change from inner-city to rural over a few kilometers. On the other hand, the total differential between center and periphery in traveling distances tends to be larger in the larger than in smaller cities, since the centers of the former are attracting labor and visitors from a larger hinterland (cf. Christaller, 1933/1966). In a Danish context, Hartoft-Nielsen (2001a) thus found traveling distances by car among residents on the metropolitan fringe to be on average four times as long as among inner-city dwellers in the Copenhagen region, three times as long in the three other larger Danish cities Århus, and two and a half times as long in four medium-sized and smaller Danish provincial towns. The total difference in the average traveling distances of central and peripheral residents of course also depends heavily on the general mobility level of the population. For example, the center-periphery difference in traveling distance in Hangzhou Metropolitan Area was only about one eighth of that found among residents of Copenhagen Metropolitan Area (a similar difference between the city regions was also found in the mean traveling distances among

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all respondents). On the other hand, while traveling distances increased with increasing distance from dwelling to the city center until the latter distance exceeded 40 km in Copenhagen Metropolitan Area, the curve leveled out already at some 8-10 km from the city center of Hangzhou (Næss, 2009a).

Based on experience from ~~five-four~~ method-wise comparable Nordic studies (~~mainly in Scandinavian urban regions but also including a Chinese urban region~~), Figure 1 shows how the average daily traveling distance by motorized modes of travel has been found to vary with the distance from the dwelling to the city center. In the figure, the effects of residential location have been controlled for socioeconomic and demographic variables (and in the metropolitan area of Copenhagen ~~and Hangzhou~~ also for transport-related residential preferences), but not for car ownership or attitudes to car travel.

Figure 1: Relationships between residential location and traveling distance by motorized modes found in ~~five-four~~ urban regions. Sources: Nielsen, 2002, pp. 238 and 260 (Aalborg); and data files from studies published in Author, 2009b (Copenhagen Metropolitan Area); Author, Røe & Larsen, 1995 (Greater Oslo); ~~Næss, 2010 and 2007a (Hangzhou Metropolitan Area);~~ and Author & Jensen, 2004 (Frederikshavn).



2.9. Location of workplaces and retail at a city/metropolitan scale Workplace location and travel behavior

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Compared to the large body of literature on residential location and travel, considerably fewer among the Nordic studies have addressed the impacts of workplace location on travel behavior (Table 5) location on the employees' commuting patterns (or visitor's travel).

Many planners have believed that decentralization of jobs to the suburbs would reduce commuting distances, since suburbanites could then be employed at workplaces close to their residential neighborhood. This has been an important underlying assumption of planning principles such as 'mixed-use', 'jobs-housing balance', and to some extent also the New Urbanism ideas. However, in contemporary specialized and high-mobility societies, people do not choose jobs (or recruit workers) mainly from within their local district. Several studies in different countries over the latest couple of decades have shown that job decentralization from inner to outer parts of cities and metropolitan areas has not contributed to reducing average commuting distances (Cervero & Landis, 1992; Hanssen, 1993; Næss & Sandberg, 1996; Hartoft-Nielsen, 1997 and 2001; Strømme, 2001; Yang, 2005; Næss, 2007b; Aguilera et al., 2009). Admittedly, according to some studies employment decentralization has reduced commuting times (Gordon et al., 1991; Cervero & Landis, 1992; Giuliano & Small, 1993). This has, however, mostly to do with the generally higher shares of fast modes of travel and higher driving speeds in the suburbs than in the inner city. In urban areas with a highly decentralized pattern of residence, average commuting distances might, according to Giuliano & Small (1993), still be shorter if the workplace is located in outer areas rather than in the city center.

Higher local jobs-housing balance has in some studies been found to reduce commuting distances among the residents of the areas where new jobs have been established and among the workers of the areas where new housing has been added (Nowland & Stewart, 1991; Frank & Pivo, 1994). However, for those employees who are not local residents, decentralization of jobs to predominantly residential suburbs may result in longer commutes. If the workplaces in question recruit workers from a wide catchment area, this increase may well outweigh any reduction in commuting distances among the local residents.

Theoretically, the proportions of commuting trips carried out by different modes of travel could be expected to be influenced to a considerable extent by the location of the workplace. In most cities, the lines of the public transport radiate from the center to the periphery. Distinct from most suburban locations, downtown can normally be accessed from all directions without any need for transfer. As mentioned in section 2, the central area is therefore usually the part of the city where accessibility by public transport is at its highest. On the other hand, accessibility by car is at its lowest in the inner city due to a high frequency of street crossings, generally narrower streets, and limited parking availability. Compared to workplaces in the suburbs, a central workplace location therefore has a higher accessibility by public transit and a lower accessibility by car. Due to the normally higher population densities in the inner city, central workplaces may also have higher shares of employees living within acceptable walking or biking distance.

In line with this, several studies have found Common to these studies is, however, the finding that lower proportions of the employees commute by car commuters and higher shares of employees traveling/travel by public transit, bicycle or by foot on their journey to workplaces located in the inner-city than to suburban jobsites (Monsen, 1983; Newman & Kenworthy, 1989; Cervero & Landis, 1992; Hanssen, 1993; Lahti-Martamo, 1995; Author & Sandberg, 1996; Hartoft-Nielsen, 2001b; Strømme, 2001; Schwanen et al., 2001; Yang, 2005; Author, 2007b; Aguilera et al., 2009).

In particular, a strong center-periphery gradient has been found for office workplaces. In a study of 52 offices in Copenhagen Metropolitan Area, Hartoft Nielsen (2001b) found that the proportion of employees commuting by car tended to increase from 40-45 % at downtown workplaces to 80 % when the distance between the workplace and downtown was 30 km. In addition, a clear effect of proximity to urban rail stations could be seen. Among the inner-city workplaces located closest to main urban rail stations, the proportions of car commuters were only 10-25 %. In the outer areas, proximity to a junction urban rail station typically reduced the proportion of car commuters from 75-85 % to 40-60 %. Similar differences between center and periphery have been found in Helsinki in Finland (Martamo, 1995) and in Oslo and Trondheim in Norway (Monsen, 1983, Author & Sandberg, 1996; Strømmen, 2001). In Oslo, a clear separate effect of the level of public transit services and parking availability at the workplace has been demonstrated in a study of workplaces relocating to a new site at similar distance from the city center as the old locations (Tennøy & Lowry, 2008). In Danish provincial cities, a center-periphery gradient for the modal split has also been found, yet with a smaller difference between city center and suburb in the share of car commuters than in Copenhagen Metropolitan Area (Hartoft-Nielsen, 2001b; Møller & Author, 2000).

Some planners have believed that the higher proportion of car trips to suburban jobs would be compensated by shorter commuting distances, since suburban workplaces might recruit a high proportion of their employees from nearby residential neighborhoods. However, in the Nordic studies, there is little evidence of any such overall tendency. For office workplaces, average commuting trips instead appear to increase slightly the more peripherally the jobs are located (Hartoft-Nielsen, 2001b; Strømmen, 2001).

For other types of workplaces than offices, the picture is more nuanced. While office workplaces are often highly specialized, less specialized workplaces (e.g. within retail, primary education, kindergartens and health care) are may more often be able to recruit employees locally. Among residents of Copenhagen Metropolitan Area with shorter education than the median, commuting distances thus tend to increase the closer to the city center the workplace is located, whereas an opposite tendency can be seen among those with education above the median. In total for all types of workplaces, the longest mean commuting distances were found among employees located some 10-25 km from the city center, with shorter journeys to work among those working more centrally as well as those working in the outermost parts of Copenhagen Metropolitan Area (Author, 2007b). This pattern cannot, however, be taken as a general rule. In Helsinki, Martamo (1995) has found a nearly opposite pattern, with the longest commutes to centrally located jobs and to jobs in outer-suburban employment centers at the main roads, with shorter journeys among employees of workplaces in the inner suburbs. Yet, similar to Copenhagen, commuting distances tended to drop when the distance from the jobsite to the city center of Helsinki increased beyond some 20-25 km.

In Copenhagen Metropolitan Area, the differences in commuting distances among different educational groups also translate into corresponding differences between employees with high and low education in the ways in which workplace location affects modal split. The proportion of car commuters among respondents with a low education was thus lowest and the proportion of walk/bike commuters highest at workplaces located between 15 and 28 km from downtown Copenhagen. Among respondents with a high education, the lowest share of car commuters and the highest share of non-motorized commuting were found at workplaces located less than 6 km from downtown (Author, 2007b), similar to the distribution found in Hartoft-Nilsens (2001b) study of employees at office workplaces, with a higher share of employees thus working within acceptable walking or biking distance. In Copenhagen Metropolitan Area, population is generally more

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decentralized than the jobs, and among suburbanites, commuting distances are on average shorter to suburban jobs than to workplaces in the inner city (Næss, 2007b). In the latter study, the proportion of car commuters among respondents with a low education was lowest and the proportion of walk/bike commuters highest at workplaces located between 15 and 28 km from downtown Copenhagen. Among respondents with a high education, the lowest share of car commuters and the highest share of non-motorized commuting were found at workplaces located less than 6 km from downtown (Næss, 2007b), similar to the distribution found in Hartoft-Nilsens study of employees at office workplaces.

For several categories of businesses, the trips generated by visitors are dominant, compared to the employees' journeys to work. This applies to, for example, shops, schools and other types of public and private service. The transport consequences of the location of visitor attracting activities will vary with the degree of specialization of the function in question. The more specialized the function is and the larger hinterland from which the visitors come, the more favorable a central location will probably be.

Exceptions from the conclusion that a central workplace location gives the least use of energy are functions clearly directed towards the local neighborhood—for example grocery stores, post-offices, elementary schools, secondary schools and kindergartens. For such functions, short distances for pupils and visitors are more important than the employees' journeys to work. Thus, these sorts of functions will create least traffic if located close to residential areas, for instance in local centers (Christaller, 1933/1966). For visitor-attracting, non-specialized functions with a primarily local catchment area, a decentralized location interspersed with residential areas seems to be the most favorable from an energy point of view (Næss, Røe & Larsen, 1995; Nielsen, 2002). Examples of this kind of function are grocery stores, post offices, elementary schools, secondary schools and kindergartens.

Workplaces that generate much truck traffic, cover a large area per employee or visitor, and/or are noisy and polluting should of course not be located downtown. According to the Dutch ABC guidelines for environmentally sound workplace location, these kinds of workplaces should preferentially be located in the suburbs with good access to the highway system and possible with a rail sidetrack for freight trains. Workplaces with many employees or visitors per area unit and low requirements of goods transport should, in line with the above, be located close to the city center or other major public transport nodes. In addition, regulations setting maximum limits for the ratio of parking places to the number of employees and visitors should be adopted in these areas (Verroen et al., 1990).

Table 5: Nordic studies investigating the influence of workplace location at a city/metropolitan scale on travel behavior

<i>Reference</i>	<i>Main influential urban form variables (any standardized regression coefficients¹⁰ in parenthesis)</i>	<i>Main categories of control variables</i>	<i>Addressing the 'self-selection problem'?</i>	<i>Car ownership as control variable?</i>	<i>Main argument</i>
Monsen (1983)	Distance to the city center	None	Not relevant	No	Relocation of workplaces from inner districts to the outskirts of Greater Oslo has resulted in increased shares of car travel and somewhat longer commuting distances
Hanssen (1993)	Distance to the city center	None	Not relevant	No	Relocation of branches of an insurance company from inner districts of Oslo to a common site at a suburban local center has resulted in increased shares of car travel
Martamo (1995)	Distance to the city center	No	Not relevant	No	Employees of workplaces located in the central parts of Helsinki metropolitan area have longer commuting distances than employees working in the inner suburbs. Employees of outer-suburban employment centers along the main roads have commuting distances as among inner-city employees. Less clear patterns in the other Finnish urban regions
Author & Sandberg (1996)	Distance to the city center (0.252***)	Demographics and socioeconomics	Not relevant	Yes	Workplace location close to the city center of Oslo contributes to lower share of car commuting, higher share of commuting by public transport and to lower energy use for commuting.
Møller & Author (2000)	Distance to city center***	A few socioeconomic variables	Not relevant	No	Higher likelihood of commuting by car if the workplace is located far away from the city center of Aalborg
Hartoft-Nielsen (2001b)	Distance to city center (0.59*** for Copenhagen Metropolitan Area)	None	Not relevant	No	Higher proportion of commuting trips by car, lower proportion of commutes by transit, longer traveling distances by car and longer overall traveling distances among employees of workplaces located far away from the city center of Copenhagen. Similar, but weaker, effects in the Danish provincial cities of Århus, Odense, Aalborg and Vejle.
Strømme (2001)	Location according to the Dutch ABC criteria	Demographic and socioeconomic	Not relevant	No	Lower proportion of car commuting and higher proportion of commuting by public transport to workplaces located in A-areas (close to the city center of Trondheim, where accessibility by public transit is high and availability of parking is low).
Tennøy & Lowry (2008)	Parking availability and public transit accessibility	No	Not relevant	No	Reduced proportions of car commuting among employees of four research institutes in Oslo relocating to a site with higher accessibility by public transit and lower limited parking availability. (Average distance to city center remained almost the same.)

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For several categories of businesses, the trips generated by visitors are dominant, compared to the employees' journeys to work. This applies to, for example, shops, schools and other types of public and private service. The Nordic studies of transport impacts of the location of service facilities have concentrated on the location of shopping malls (Table 6). In all these studies (two Norwegian and one Swedish), out-of-town location of shopping malls has been found to contribute to higher shares of car trips and more vehicle kilometers by car (Svensson, 1998; Hanssen & Fosli, 1998; Engbretsen et al., 2010). According to the former of these studies, the distance traveled by car for

shopping in Linköping, Sweden increased by 50% due to the establishment of three out-of-town shopping malls.

Table 6: Nordic studies investigating the influence of the location of shopping malls at a city/metropolitan scale on travel behavior

<i>Reference</i>	<i>Main influential urban form variables (any standardized regression coefficients¹¹ in parenthesis)</i>	<i>Main categories of control variables</i>	<i>Addressing the 'self-selection problem'?</i>	<i>Car ownership as control variable?</i>	<i>Main argument</i>
Hanssen & Fosli (1998)	Distance to local center	None	No	No	Location of a shopping mall close to a suburban center in the outskirts of Greater Oslo contributes to lower share of car trips and less vehicle km by car per customer than exurban location far away from any such center.
Svensson (1998)	Exurban vs. intra-urban location	Before-and-after study	No	No	As a result of the establishment of three out-of-town shopping malls in Linköping, the distance traveled by car for shopping in Linköping increased by 50%
Engebretsen, Hanssen & Strand (2010)	Distance to city center	None	Not relevant	No	Higher share of public transit and non-motorized shopping trips, and lower share of car trips, among customers of shopping malls in or around Norwegian cities above 50,000 inhabitants if the malls are located close to the centers of the respective cities

3-10. Population density at a city scale **Density**

Inspired by Newman & Kenworthy's (1989) study of urban density and gasoline consumption in 32 cities worldwide, investigations into the relationships between city-scale urban density and energy use for transportation in Nordic cities were carried out in the first half of the 1990s (Table 7). When discussing the influence of travel from population density at a city-wide scale, it is important that the area within which density is demarcated is measured in an appropriate way. The relevant area is the urbanized land (including built-up areas, infrastructure as well as parks and other smaller intra-urban open areas). Such demarcations were used in the Nordic studies as well as in Newman & Kenworthy's earlier investigation. In the most comprehensive of the Nordic studies, 22 cities in Norway, Denmark, Sweden and Iceland were investigated, with energy data based on fuel sales and electricity use for public transit services. In line with theoretical expectations (cf. section 2), a much of the debates around the influence of urban form on transport has focused on density. In their pioneering study of 32 cities in America, Europe, Asia and Australia, Newman & Kenworthy (1989a) found a strong, hyperbola-shaped relationship between gasoline consumption per inhabitant and urban population density. As could be expected from theoretical considerations (cf. section 2), gasoline consumption was considerably higher among residents of low density American cities than in high density Asian cities. However, due to the political, economic, social and cultural heterogeneity of the cities included in their sample, all this difference could obviously not be attributed to density variations. Some critics have used this fact as an argument to dismiss Newman & Kenworthy's results altogether (e.g. Gordon & Richardson, 1989). However a relationship between density and gasoline consumption was found also when limiting the comparison to the ten US American cities of their sample (Newman & Kenworthy, 1989b). Also, in an updated study including 46 cities at a world wide scale, Newman & Kenworthy (1999) concluded that density still

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~~matters after controlling for some other variables, notably fuel price and income.~~ A clear relationship between urban population density and energy use for transport was ~~also found in a study of 22 Nordic cities, where~~ (Author, Sandberg and Røe, 1996). ~~This relationship was~~ still present when controlling for a number of other urban form and socio-economic variables (including population size and income level). A ~~separate similar~~ study of 97 Swedish cities and towns also showed clearly higher levels of energy use for transport in low-density than in high-density cities, also after controlling for other key factors of influence (Author, 1993).

Table 7: Nordic studies investigating the influence of population density at a city scale on energy use for transportation

Reference	Main influential urban form variables (any standardized regression coefficients ¹² in parenthesis)	Main categories of control variables	Addressing the 'self-selection problem'?	Car owner-ship as control variable?	Main argument
Author (1993)	Population density within demarcations of continuous urbanized land (0.70***) (Energy use for transport)	Population size, income level, proportions living in the main town of the municipality and in rural areas	Not relevant	No	Among Swedish municipalities including a town of at least 10,000 inhabitants, high mean population density within the demarcations of the urbanized areas contributes to lower energy use for transportation.
Author, Sandberg & Røe (1996)	Population density within demarcations of continuous urbanized land (0.370***) (Energy use for transport)	Population size, composition of trades, income, other socioeconomics, exurban commuting, and degree of concentration of the urban population towards the city center	Not relevant	Yes	Among 22 Nordic cities, high population density within the demarcations of the urbanized areas contributes to lower energy use for transportation.

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These results square well with earlier studies such as Keyes' (1976, 1982) comparison of fuel consumption in 49 American metropolitan areas in the 1970s – as well as more recent analyses, including an expansion of Newman & Kenworthy's sample to 84 cities (Kenworthy, 2003; Lefèvre, 2010).

4. ———— When discussing the influence of travel from population density at a city wide scale, it is important that the area within which density is demarcated is measured in an appropriate way. The relevant area is the urbanized land (including built up areas, infrastructure as well as parks and other smaller intra-urban open areas). Such demarcations were used in all the above mentioned studies. However, in some other studies, population density was measured within administrative territories (e.g. one or more municipalities) including large continuous non-urbanized areas. In some such studies (e.g. Gordon, 1997), no relationship worth mentioning was found between population density and transport. However, whether or not a municipality includes a large or a small rural area in addition to its urbanized land is completely irrelevant to the causal mechanisms by which urban population density is assumed to influence travel. When analyzing the impact of urban population density at a scale exceeding that of the continuous urbanized area of the main city, density should therefore be measured as the total population within the urban settlements of the

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urban region, divided by the total urbanized area of these settlements. This was the way population density was measured in Keyes' above-mentioned study of American metropolitan areas.

5. Much of the debates around the influence of urban form on transport has focused on density. In their pioneering study of 32 cities in America, Europe, Asia and Australia, Newman & Kenworthy (1989a) found a strong, hyperbola shaped relationship between gasoline consumption per inhabitant and urban population density. As could be expected from theoretical considerations (cf. section 2), gasoline consumption was considerably higher among residents of low density American cities than in high density Asian cities. However, due to the political, economic, social and cultural heterogeneity of the cities included in their sample, all this difference could obviously not be attributed to density variations. Some critics have used this fact as an argument to dismiss Newman & Kenworthy's results altogether (e.g. Gordon & Richardson, 1989). However a relationship between density and gasoline consumption was found also when limiting the comparison to the ten US American cities of their sample (Newman & Kenworthy, 1989b). Also, in an updated study including 46 cities at a world wide scale, Newman & Kenworthy (1999) concluded that density still matters after controlling for some other variables, notably fuel price and income. In recent years, most studies of relationships between urban density and travel have focused on the neighborhood scale instead of the city as a whole (see, e.g., Handy & Clifton, 2001; Chatman, 2005; Rajamani et al., 2003; Handy et al., 2005; Boarnet & Crane, 2001). For example, the density component of "the three D's" coined by Cervero and Knoopelman (1997) as key urban form characteristics influencing travel referred mainly—implicitly or explicitly—to the local urban neighborhood or district. Although many studies have found correlations between density measured at this level and travel behavior, these correlations are most considerably weakened or even vanish once control is made for the location of the neighborhood relative to the city center (see, e.g., Næss, 2011). In Ewing and Cervero's (2010) meta analysis, too, only small elasticities were found between vehicle miles traveled and, respectively, population and job densities.

6. This should, however, not lead us to conclusion that a high local area density contributes only weakly to reduce car traffic and emissions from transport. Local area densities add up to the overall density of the city, which has, as shown above, considerable influence on travel behavior. High local area density also strengthens the population base for local service facilities and thus increases the likelihood that such destinations can be found within walking distance. Several empirical studies have, in line with this, concluded that higher residential densities do promote higher shares of non-motorized trips in connection with non-work activities (Handy & Clifton, 2001; Rajamani et al., 2003; Handy et al., 2005; Næss, 2006a). Such an increase in the share of local walking (or biking) trips is important from a public health perspective (Frank et al., 2004; Ewing et al., 2006), although the travel mode for these short trips does not in itself exert much influence on the overall number of vehicle kilometers traveled. However, if availability of local shops and other services within walking distance makes some residents choose these facilities instead of driving to facilities outside the local neighborhood, the overall amount of motorized can be reduced to a higher extent. A study in the Central Puget Sound in USA thus found evidence of a fairly high reduction in vehicle miles traveled attributable to higher accessibility of facilities within the neighborhood, where neighborhood accessibility was measured as an index combining density, land use mix, and street patterns (Krizek, 2003).

7. Neighborhood design

3. Neighborhood scale street pattern is an urban structural variable often used in American studies investigating relationships between urban built environment and travel behavior:

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Compared to the curvilinear and cul-de-sac street patterns typical for suburban neighborhoods planned according to modernist principles, grid-shaped street networks facilitate more direct access to local destinations and can thus bring a larger number of local facilities within acceptable walking (or biking) distance (Handy et al., 1998). In several American studies (e.g. Cervero, 2003; Frank, 2003), the amount of car travel has been found to be lower among residents living in neighborhoods characterized by grid-shaped than by other types of street patterns. However, neighborhoods with grid-shaped street patterns are usually in the inner parts of cities and metropolitan areas. Few of the studies attributing differences in travel behavior to local street design characteristics seem to have controlled for this circumstance. In one of the few studies comparing the influences of metropolitan-level and neighborhood-level urban form characteristics on travel behavior (Næss, 2011), the relationship between the local-level street structure on traveling distance by car disappeared as soon as control was made for the location of the residence relative to the metropolitan center. This gives rise to suspicion that the corresponding relationship found in some American studies might perhaps reflect the location of the residential areas rather than the shape of the local street network.

8.11. Centralization vs. decentralization at different geographical levels a regional scale

As shown in section 8.5, at the level of individual cities or metropolitan areas there is strong evidence that residential location close to downtown contributes to reduce the amount of travel in general and travel by car in particular. Some professionals maintain that this will also be the case at the level of larger regions (for instance a county or a province), from a line of argument that there will be a lot of crisscrossing transport between the different local communities in regions with a decentralized population pattern. However, evidence from the Nordic countries (Table 8) suggests that centralization at a wider regional scale may not entail the same benefits as centralization within a metropolitan area or a city, seen from a perspective of reducing the energy use and emissions from transport.

~~several studies indicate that the amount of travel may be quite modest when people live sufficiently far away from large urban centers. According to Breheny (1992), studies of the degree of self-containment of jobs in British urban settlements suggest that if new satellite settlements are to be energy efficient, they must either be small and remote, large and remote, or very close to existing urban areas. In the earlier above-mentioned study of Copenhagen Metropolitan Area (cf. section 8.5), a slight tendency of reduced travel distances could be observed among residents of the very most peripheral parts, i.e. more than 45 km away from the city center (Author, 2006a). In a study of three Danish provinces, Author & Johannsen (2003) found that the amount of motorized travel tended to increase at a steady pace with increasing distance from home to the center of the closest main town distance from the dwelling to the town center of the closest one among the county's 4–6 largest towns, up to a distance of some 15 to 25 kilometers. Beyond that distance, traveling distances began to decline again, reaching levels in the most peripheral locations only slightly above the levels found among the residents living closest to the center of one of the county's main towns.~~

A study of commuting distances in Finnish municipalities points in the same direction. Here, people living in rural and peripheral municipalities were found to usually have shorter commuting distances than those ~~who living~~ in the suburbs of the largest cities (Martamo, 1995). Similarly, an investigation of transport energy use in Swedish regions found that the energy use tended to increase the more the regional population was concentrated around the largest town of the region.

Contrary to expectations, a high degree of urbanization, meaning that the proportion of the regional population living in rural areas and small settlements is small, tended to increase the use of energy for transport. On the other hand, a high population density within the cities contributed (as might be expected) to reduced energy use. (Author, 1993).

The above-mentioned studies of traveling distances at regional or provincial level clearly point at 'distance decay' in the attractiveness of a large center. Beyond the range of influence of the largest centers, most people are likely to orient themselves to a higher extent to smaller, more local centers, even if the job opportunities and selection of service facilities are narrower than in the big city.

Table 8: Nordic studies investigating the influence of centralization vs. decentralization at a regional scale on travel behavior and energy use for transportation

<i>Reference</i>	<i>Main influential urban form variables (any standardized regression coefficients¹³ in parenthesis)</i>	<i>Main categories of control variables</i>	<i>Addressing the 'self-selection problem'?</i>	<i>Car ownership as control variable?</i>	<i>Main argument</i>
Larsen et al. (1982)	Location of the dwellings relative to centers at different levels in a center hierarchy	Unclear, but probably none	No	No	Energy use for transport in Denmark increases with increasing distance from the dwelling to the closest main city or town center, with the lowest energy use in the centers of the largest cities. On the other hand, energy use for transport is generally higher in the most urbanized regions of the country
Author (1993)	Degree of concentration of the regional population to the biggest city (-0.60*) (Energy use for transport)	Population density within cities and urban settlements, income level	No	No	At the regional level, decentralized concentration appears to be the most energy efficient pattern, i.e. a settlement structure where a moderate part of the regional population is concentrated to the biggest town, while each town and settlement has a high population density.
Martamo (1995)	Distance from dwelling to the center of the closest larger city	None	No	No	Commuting distances in Finland tend to increase with increasing distance from home to the closest main city center up to a 'turning point', beyond which further increase of the distance to the city center contributes to reduce the mean commuting distances. These 'turning points' are further away from the city centers, the larger the city is. In the most remote rural regions, commuting distances are on average short.
Author & Johannsen (2003)	Distance from dwelling to the center of the closest larger town (0.115* - 0.163***)	Income, age, household composition and size, vehicle ownership	No	Included ¹⁴ as well as not included	Increasing distance from the dwelling to the center of the closest larger town in the counties of North Jutland, Ringkjøbing and Vejle up to 15-20 km contributes to increase the amount of motorized travel, but when the distance to the center of the closest town increases beyond this level, the amount of motorized travel tends to decrease.
Author (2006a)	Distance from dwelling to the main metropolitan city center	Demographics, socioeconomics, transport attitudes, environmental attitudes, residential preferences, local area density	Partly	Included as well as not included	When the distance from the dwelling to the city center of Copenhagen exceeds 40-45 km, mean traveling distances decrease slightly.

This might form a basis for the development of more local lifestyles and activity patterns among people living in the peripheral parts of a region. On the other hand, with an increasingly mobile population, the range of influence of large centers will probably expand. According to Brotchie (1984), a decentralized settlement structure will be the most energy efficient and least transport-requiring one if the level of physical mobility in the society is low. In such a situation, the distance decay will be high, with rationales of distance minimizing outweighing those of choosing the best facility. In a high-mobile society, however, the deterrent of distance will be low, with rationales of choosing the best facility generally dominating over distance minimizing (within some threshold of acceptable travel time). A high degree of interaction and functional integration between the different settlements of a region could then be expected. In such a situation, a decentralized settlement pattern will, according to Brotchie, be the most transport- and energy-demanding one. If residential development in peripheral rural areas and villages in a high-mobile society is to be compatible with modest average amounts of travel, the distances to the closest cities (and in particular major metropolitan centers) must therefore be quite long, and longer the stronger is the attraction of the main center.

9.12. Concluding remarks Discussion

The Nordic studies reviewed in this paper provide evidence that several urban form characteristics influence the inhabitants' amount of transport and their choice of means of conveyance. The rationales for location of activities, choice of transport modes and route choice identified in qualitative research make up important links in the mechanisms by which urban structures influence travel behavior. Most of these rationales either contribute actively to strengthen the relationships between urban form and travel, or are neutral as regards these relationships. Notably, the tendency of inhabitants in modern cities to emphasize (within some threshold distances) the possibility of choosing among facilities rather than proximity means that the amount of travel is influenced to a higher extent by the location of the residence in relation to concentrations of facilities, rather than the distance to the closest single facility within a category. Daily traveling distances therefore tend to be more more-influenced by the distance from the dwelling to the city's main concentration of facilities (usually downtown the inner city) than by its distance to local centers. The transport rationales identified in the Nordic studies are hardly unique to the Scandinavian context. In a subsequent study of residential location and travel in Hangzhou, China, very similar transport rationales as those of the Copenhagen interviewees have been found (Author, 2009b). This similarity across widely differing contexts suggests that there may be a high degree of generality of the basic mechanisms through which urban form influences travel behavior.

The conclusions from the Nordic studies add to the quite overwhelming international evidence that urban spatial structures matter to travel behavior and are in line with what could be expected from theoretical insights within fields such as transportation geography (Tobler, 1970; Jones, 1978; Fox, 1995), time-geography (Hägerstrand, 1970) and central place theory (Christaller, 1933/1966; Berry & Garrison, 1958). However, whereas much of the research in America and parts of Europe has focused on the influences of local neighborhood characteristics on travel, the Nordic research shows effects on travel behavior mainly from urban form characteristics at a higher geographical scale: the overall population density within continuous urban areas, and the locations of residences and workplaces relative to the city-level or metropolitan center structure. These relationships also exist when taking into account self-selection based on transport-related residential preferences and when controlling for car ownership. Many inner-city residents walk, cycle or go by public transport to their daily destinations even if they have got a car at their disposal, and this reduced car usage is only to a small extent, if at all, compensated through weekend driving. This illustrates the point

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made by Kaufmann (2002) that potentials for movement (motility, according to Kaufmann's vocabulary) are not automatically realized as actual movement (observable travel). However, as shown in some of the Nordic studies, car ownership is itself influenced by residential location, and including car ownership as a control variable may therefore be inappropriate. Although many studies – internationally as well as in the Nordic countries – have treated car ownership as an exogenous control variable and thus ignored the influence of residential location on car ownership, the two-way influence characterizing this relationship is increasingly being acknowledged in the international research (Giuliano & Narayan, 2003; Schreiner & Holz-Rau, 2007, Vance & Hedel, 2008; Zegras, 2010; Aditjandra et al., 2010).

Similar strong influences of residential location relative to the city center on traveling distances (totally or by car) as those found in the Nordic studies have also been identified in a number of other cities around the world, including Paris (Mogridge 1985, Fouchier 1998), London (Mogridge, *ibid.*), New York and Melbourne (Newman and Kenworthy 1989), San Francisco (Schipper et al. 1994), Austin, Texas (Zhou & Kockelman, 2008), Athens (Milakis, Vlastos and Barbopoulos), Hangzhou (Author, 2009b and 2010) and Santiago de Chile (Zegras, 2010). These cities are all more or less monocentric. In cities with a more polycentric structure, the influence of the distance to the city center itself may be weaker. For example, in a study of Greater Oporto, Portugal, most travel behavior variables were found to be more closely related to the closest main regional retail center than to the main city center¹⁵ (Author, Silva & Pinho, 2011).

The influences of workplace location on commuting patterns found in the Nordic studies also resemble the relationships found in a number of international studies. Cities where lower proportions of car commuters and higher shares of employees traveling by public transit, bicycle or by foot have been found at inner-city than at suburban jobsites include the San Francisco Bay area (Cervero & Landis, 1992); London and other large British cities (Dasgupta, 1994); the Dutch Randstadt area (Schwanen et al., 2001); Atlanta and Boston (Yang, 2005); and Paris (Aguilera et al., 2009). Several studies in cities in other parts of the world also support the conclusion from the Nordic studies that job decentralization from inner to outer parts of cities and metropolitan areas usually does not contribute to reducing average commuting distances (Cervero & Landis, 1992; Yang, 2005; Aguilera et al., 2009). Admittedly, according to some studies employment decentralization has reduced commuting *times* (Gordon et al., 1991; Cervero & Landis, 1992; Giuliano & Small, 1993). This has, however, mostly to do with the generally higher shares of fast modes of travel and higher driving speeds in the suburbs than in the inner city.

The influence of the population density for the city as a whole on energy use for transportation found in the Nordic studies squares well with the results of Newman & Kenworthy's (1989) much-cited study as well as earlier studies such as Keyes' (1976) comparison of fuel consumption in 49 American metropolitan areas in the 1970s and more recent analyses, including an expansion of Newman & Kenworthy's sample to 84 cities (Kenworthy, 2003; Lefèvre, 2010). The Nordic finding that local-area density shows much weaker relationships with travel behavior is also in line with international experience. For example, in Ewing and Cervero's (2010) meta-analysis, only small elasticities were found between vehicle miles traveled and, respectively, population and job densities. Moreover, in many of the international studies where the impact of local-area density has been assessed, no control has been made for the location of the neighborhood relative to the city center (e.g. van Acker et al., 2007). This should, however, not lead us to conclude that a high local area density contributes only marginally to reduce car traffic and emissions from transport. Local area densities add up to the overall density of the city, and a high neighborhood-scale density

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strengthens the population base for local service facilities and thus increases the likelihood that such destinations can be found within walking distance.

Interestingly, none of the Nordic studies appear to have investigated the influence of degree of mixed land uses in the local neighborhood (the Diversity component of 'the three D's' emphasized by Cervero and Knockelman, 1997). This omission may – at least partly – be based on an implicit assumption that people living in a neighborhood will neither necessarily be employed at the workplaces in the same neighborhood (i.e. that the local jobs-housing balance may not be very important) nor primarily use the local shopping and leisure facilities, cf. the transport rationales discussed in section 5. Studies in other European cities (e.g. Milakis et al., 2008) suggest that the local jobs-housing balance may exert some influence on mean trip lengths by car as well as the share of public transport (the latter probably because jobs in a residential neighborhood increase the population base for a higher level of public transport services). This appears to be true across city sizes as well as different national contexts. Although most of our examples are from the Nordic countries, the mechanisms through which urban structure affects travel behavior are likely to be present in a wider international context as well. Our results thus seem to be of a high generality.

A high population density implies shorter average distances between residences, workplaces and service facilities than in a city with a dispersed pattern of development. Because most cities have higher concentrations of jobs and services in the inner than in the outer areas, inner-city residents tend to travel shorter daily distances than suburbanites and are therefore also able to carry out a higher share of their trips by non-motorized modes. The inner city is also usually the part of the city where accessibility by public transport is at its highest, whereas accessibility by car is at its lowest due to a high frequency of street crossings, generally narrower streets, and limited parking availability. Public transport and non-motorized modes are therefore usually better able to compete with the car as travel mode for commutes to inner-city than suburban workplaces.

The Nordic studies addressing possible influences of neighborhood-scale street pattern and travel behavior have either found no such relationship whatsoever or relationships opposite to those found in American studies (e.g. Cervero, 2003; Frank, 2003). This gives rise to suspicion that the relationships between street pattern and travel found in some American studies might perhaps reflect the location of the residential areas rather than the shape of the local street network. In Ewing and Cervero's (2010) meta-analysis, street intersection density and street connectivity were found to be almost as influential as distance to downtown or employment concentrations on the number of vehicle kilometers traveled. However, based on the transport rationales discussed in section 5, it is difficult to justify why local-area street design would exert any strong influence on overall traveling distances by car. Instead, the location of the residence relative to main concentrations of facilities (in particular employment) could be expected to exert far stronger influence on traveling distances in general and car travel in particular.

The Nordic studies suggest that while at an intra-metropolitan scale a centralized pattern of development will require the least amount of energy for transportation, decentralized concentration may be the most energy-efficient settlement pattern at a wider regional scale. According to Brotchie (1984), a decentralized settlement structure will be the most energy efficient and least transport-requiring one if the level of physical mobility in the society is low. In such a situation, the distance decay will be high, with rationales of distance minimizing outweighing those of choosing the best facility. In a high-mobile society, however, the deterrent of distance will be low, with rationales of choosing the best facility generally dominating over distance minimizing (within some threshold of acceptable travel time). If a peripheral settlement is to function in a self-contained way in a high-

mobility society, it must be located outside the catchment area of competing centers. Thus, Banister (1992) found that traveling distances were shortest and the proportion of walking highest in the most urbanized of six investigated parishes in the generally densely populated Southern England, while the most rural parish was distinguished by long trips and a high proportion of car driving. If residential development in peripheral rural areas and villages in a high-mobile society is to be compatible with modest average amounts of travel, the distances to the closest cities (and in particular major metropolitan centers) must therefore most likely be quite long, and longer the stronger is the attraction of the main center (Breheny, 1992).

~~The rationales for location of activities, choice of transport modes and route choice identified in qualitative research make up important links in the mechanisms by which urban structures influence travel behavior. Most of these rationales either contribute actively to strengthen the relationships between urban form and travel, or are neutral as regards these relationships. Notably, the tendency of inhabitants in modern cities to emphasize (within some threshold distances) the possibility of choosing among facilities rather than proximity means that the amount of travel is influenced to a higher extent by the location of the residence in relation to concentrations of facilities, rather than the distance to the closest single facility within a category. Daily traveling distances therefore tend to be more influenced by the distance from the dwelling to downtown than by its distance to local centers.~~

Based on the studies presented in this paper, the following urban developmental policies could be recommended in order to help reduce the amount of travelling, and increase the share of the less polluting modes of transportation:

- ~~avoid urban sprawl~~
- ~~increase the proportion of the population living in the inner and central areas of the city~~
- ~~increase the proportion of workplaces located in the inner and central areas of the city~~
- ~~ensure a sufficiently high density in new developmental areas to facilitate a good provision of local service and a good public transport provision.~~

~~Such principles are also very well compatible with energy conservation in buildings, as the building types associated with low density, suburban residential areas require considerably more energy per inhabitant for heating and cooling than the housing types characteristic of inner city, medium or high density living. A less area-demanding urban development also contributes to the sustainability objectives of protecting soil for food production as well as natural areas and biodiversity in the surroundings of the city.~~

~~Seen in the light of current policies pursued in many countries (see, e.g., European Environmental Agency, 2006), some people might find the recommendations above unrealistic and even naïve. However, there are indications from several North European cities of a gradual change towards more sustainable land use development. For example, in Oslo and to some extent in Copenhagen, land use policies have during recent decades been explicitly geared towards limiting traffic growth, and especially in Oslo the period since the late 1980s has been characterized by concentrated and compact urban development (Næss et al, 2010 and 2011). Cities are thus not deemed to continue to sprawl, as claimed by some debaters (e.g. Breheny, 1996). The purpose of the present paper has been to provide planners and urban policy-makers with information about the likely impacts of~~

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urban land use changes to the amount of travel and the modal split between different means of transport. In cities where there is political willingness to take the sustainability challenges seriously the urban planning strategies listed above could make an important contribution.

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Notes

¹ Due to language barriers, the author's knowledge of Finnish studies may not be complete.

² Population figures refer to the contemporary (2010 or 2011) number of inhabitants, which may differ from the population size at the year of investigation.

³ In the small town of Frederikshavn, the number of workplaces outside the city center and its closest surroundings was quite limited, and the option of choosing a local facility was simply not available in some of the suburbs and satellite settlements.

⁴ Levels of significance are indicated by asterisks: <math><0.05=<math>*<math>; <math><0.01=<math>*<math>*<math>; <math><0.001=<math>*<math>*<math>*<math>.

⁵ The coefficient shown refers to an analysis *not* including car ownership as control variable.

⁶ See note 4.

⁷ See note 4.

⁸ See note 5.

⁹ See note 5.

¹⁰ See note 4.

¹¹ See note 4.

¹² See note 4.

¹³ See note 4.

¹⁴ See note 5.

¹⁵ The distance to the main city center still influences travel behavior indirectly since the likelihood of living close to a main regional retail center is higher in the inner than in the outer parts of Greater Oporto.

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